

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property
Organization
International Bureau



(43) International Publication Date
29 January 2004 (29.01.2004)

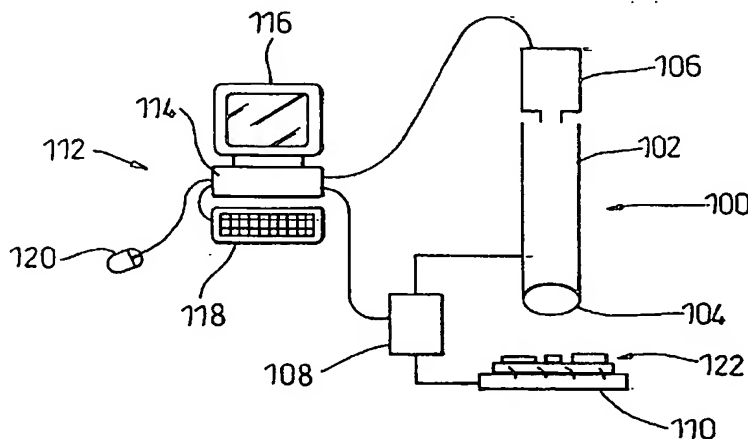
PCT

(10) International Publication Number
WO 2004/010380 A2

- (51) International Patent Classification⁷: G06T 7/00 (74) Agent: BARKER BRETTELL; 138 Hagley Road, Edg-
baston, Birmingham B16 9PW (GB).
- (21) International Application Number: PCT/GB2003/003052 (81) Designated States (*national*): AE, AG, AL, AM, AT, AU,
AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU,
CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH,
GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC,
LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW,
MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC,
SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA,
UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.
- (22) International Filing Date: 14 July 2003 (14.07.2003) (84) Designated States (*regional*): ARIPO patent (GH, GM,
KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW),
Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM),
European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE,
ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO,
SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM,
GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).
- (25) Filing Language: English
- (26) Publication Language: English
- (30) Priority Data: 0216641.1 18 July 2002 (18.07.2002) GB
- (71) Applicant (*for all designated States except US*): THE UNIVERSITY OF NOTTINGHAM [GB/GB]; Univer-
sity Park, Nottingham NG7 2RD (GB).
- (72) Inventors; and
- (75) Inventors/Applicants (*for US only*): SEE, Chung, Wah [GB/GB]; 16 Mount Pleasant, Oadby, Leicester LE2 4UA (GB). SOMEKH, Michael, Geoffrey [GB/GB]; 38 Ren-
frew Drive, Wollaton, Nottingham NG8 2FX (GB). PIT-
TER, Mark, Charles [GB/GB]; 4 Rushworth Court, West
Bridgford, Nottingham NG2 7LH (GB).
- Published:
— without international search report and to be republished
upon receipt of that report

[Continued on next page]

(54) Title: IMAGE ANALYSIS METHOD, APPARATUS AND SOFTWARE



(57) Abstract: An image analysis apparatus comprises a microscope (102) arranged to capture an image of a sample (122), a processor unit (114) arranged to process the image and a drive mechanism (108). The drive mechanism (108) is arranged to effect relative motion between the sample (122) and the microscope (102) typically along an optical axis of the microscope (102). The microscope (102) is arranged to capture a plurality of images (402a-404c) of the sample (122) at a plurality of points, typically, along the optical axis. Relative motion of between the sample (122) and the microscope (102) typically, along the optical axis is effected by the drive mechanism (108) and the processor unit (114) is arranged to divide each of the plurality of captured images (402a-404c) into a plurality of sub-images and select one of each of the plurality of sub-images having the best focus characteristics.

WO 2004/010380 A2



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

IMAGE ANALYSIS METHOD, APPARATUS AND SOFTWARE

This invention relates to an image analysis method, apparatus and software arranged to carry out image analysis. More particularly, but not
5 exclusively it relates to a method, apparatus and software for measuring the deformation of a substrate between an initial state and a second state,

The analysis of the deformation of objects is of importance in fields as diverse as microelectronics and medical imaging.

10

As an example only we will discuss semiconductor chip design and analysis. In microelectronics the analysis of the deformation of packaged devices, and the packaging of devices is an important tool in determining failure modes in packaged devices. A principal cause of device failure is
15 strain developing between materials having differing thermomechanical properties within the packaging. Stresses that arise from the materials' thermomechanical properties can result in delamination, hotspots and cracking within a device, all of which can lead to device failure.

20 The above mentioned modes of device failure have become more acute because of requirements for devices to operate in diverse environmental conditions, with many being required to operate at temperatures ranging from sub-zero to in excess of 100°C, and even in a domestic environment temperatures of 0°C and 50°C can be experienced by a device. Also, the
25 construction of modern electronic devices, in which structures are formed from multiple layers of differing materials with different thermomechanical properties leads to deformation with changes in temperature. Different regions of the device often have different functions, and as power dissipation increases so does the effect of
30 differential heating of devices, which leads to deformation. Power dissipation per unit volume is a factor in this context.

As deformation due to high strain regions is a major source of device failure it is important to be able to measure strain in electronic devices and their packaging. Reducing strain in devices and their packaging improves device yields during the process of manufacturing the devices and increases the mean lifetime to failure of devices in the field. The analysis of strain in devices and their packaging allows computer models to be developed, and refined, that are used in the design of the chip/device and associated packaging so as to minimise the strains in the actual manufactured devices and packaging.

It is known to use optical techniques to measure thermal deformation of devices (e.g. semiconductor chips), deformation being a measure of the strain present in a device. One known method of measuring thermal deformation is sub-image correlation. This involves obtaining images of the device both before and after deformation. Each of the images is divided into an (mxn) array of sub-images. Corresponding sub-images of the before and after deformation images are compared, for example, using a two dimensional correlation function. The location of a peak within the correlation function provides a quantitative measure of the deformation of the device that has occurred between the two corresponding sub-images. Applying the correlation function across all of the corresponding (mxn) sub-images yields a map of the in-plane deformation, or movement, of the device that has occurred between the acquisition of the two images. It is also known to incorporate, subpixel or non-integral sub-image shifting into more advanced correlation methods. This gives a sub-micron accuracy in measuring in-plane deformations. Such a method is detailed in the paper by M.C. Pitter, C.W. See and M.G. Somekh "subpixel microscopic deformation analysis using correlation and artificial neural networks," Opt. Express 8, 322-327 (2001)

Despite the great sensitivity of digital image correlation techniques they still have shortcomings associated with them. For example, image correlation techniques can usually be used to measure in-plane (x-y) deformation only. This is limiting as thermal deformation typically also
5 involves an out-of-plane (z) component that if measured and incorporated into computer models of devices would improve their accuracy.

Also out-of-plane deformation may result in part of a device or sample surface moving out of the focal plane of the imaging system. A poorly
10 focussed sub-image will lead to an error in the measurement of the in-plane deformation due to unclear feature edges, and also due to apparent movement of the surface features being correlated. In these circumstances measured movement, or at least some of it, appears to be an artefact of the different optical paths (a change in magnification can look like a
15 strain).

A problem associated with earlier image correlation techniques is that they require large magnifications to overcome inherent limitations in their analysis code. This requires short working distances that can lead to
20 heating of the optics, and consequent image distortions, when working with hot samples. Also, short focal length lenses tend to have greater lens caused aberration than longer focal length lenses.

Earlier subpixel image correlation techniques suffer from an inherent
25 problem that they employ curve fitting procedures that cannot fit over multiple textures, i.e. regions of significantly differing sample spatial structure or contrast level (the amount of differentiation, between adjacent image features). This is a particular problem for electronic device packages where multiple textures co-exist in a small area, for
30 example dark packaging material adjacent highly reflective silicon.

Another area where deformation and strain measurement is of great importance is the field of medical imaging, for example, of tumours in soft tissue. In imaging these tumours the soft tissue surrounding the tumour is palpitated. The soft tissue exhibits a uniform strain.

5 However, the hard tumour appears as a non-strained region, or a region having a strain that is lower than that of the surrounding soft tissue.

Similarly, the palpitation of muscles surrounding a bone in an ultrasound scan can yield strain images of the bone, for example when a broken bone

10 is pinned or set, in a similar manner to that of tumour imaging. Both of the above-mentioned medical uses suffer from the problems that a lack of out-of-plane measurement limits their quantitative use for the measurement, for example, of the size and/or shape of a tumour.

15 According to a first aspect of the present invention there is provided an image analysis method comprising the steps of:

- i) capturing at least two primary images of at least one part of a sample in a first state using imaging means, the at least two
- 20 primary images being captured at different focal planes;
- ii) capturing at least two secondary images of said at least one part of said sample in a second state using imaging means, the at least two secondary images being captured at differing focal planes.
- iii) selecting one of said primary images that has the best definition of
- 25 at least one feature therein using processing means;
- iv) selecting one of said secondary images which has the best definition of said at least one feature therein using processing means, and
- v) comparing the primary and secondary images selected in steps (iii)
- 30 and (iv) in order to determine the displacement, if any, of a feature.

This method has the advantage over current systems that the use of a plurality, stack, of images at a number of focal planes allows a highly correlated pair of sub-images to be determined for each area of the sample. This reduces errors in in-plane displacement measurement, as the definition of features to be compared will be maximised at a highly correlated image, thus routinely allowing sub-micron displacement measurement accuracy. Also, out-of-plane displacements of an area of the sample defined by each of the sub-images can be directly measured by the displacement of the imaging means relative to its initial position. Whilst not noise free, the reduction in errors due to poor focusing achieved using this method allows the effects lost in the noise of prior art arrangements to be recovered using this method.

It will be appreciated that there may be provided more than at least two primary and/or secondary images and each of the primary and/or secondary image may be at a different focal plane to the others. It will be further appreciated that not all of the primary and/or secondary images need be processed in the case where there are more than at least two primary and/or secondary images.

The method may include providing the primary image in the form of initial image captured by the imaging means having a single nominal focal plane depth or in the form of a composite image composed of sub-images each defining a focal plane depth. The use of a composite image reduces alignment problems as each part of the sample is referenced to respective primary images depth. This reduces the need to obtain an optically flat alignment of the sample relative to the imaging means as deformations are ascertained on a sub-image by sub-image basis. This method removes the need for accurate horizontal re-alignment of the sample following

deformation as any misalignment can be compensated for by the use of best focus secondary sub-images from different focal planes.

The method may include determining best focus primary sub-images from
5 the at least two primary images and selecting best focus secondary sub-images from the at least two secondary images. It will be appreciated that a best focus sub-image is that where features within the region are at their sharpest focus in comparison to corresponding sub-images at different focal planes. This provides for the formation of the best focus image
10 irrespective of any out-of-plane deformation exhibited by the sample.

The method may include centring the at least two secondary images about a nominal focal plane of a best focus primary image. The method may include effecting relative motion between the sample and the imaging
15 means between image capture operations, typically this will involve substantially equally spaced, stepwise motion.

The method may include measuring in-plane and out-of-plane displacements of at least one feature between a respective corresponding
20 primary image selected in step (iv) and the respective secondary image selected in step (v). The method may include measuring an out-of-plane displacement of at least one feature by multiplying a number of steps moved by the imaging means in achieving a desired secondary image quality by the step size.

25

The method may include sub-dividing each of the primary and secondary images into sub-images having an array size of between 16x16 and 64x64 pixels, a typical sub-image comprising 24x24 or 32x32 pixels. The sub-image may be as small as 2x2 pixels. Alternatively, the sub-image may be
30 of any shape, i.e. they need not be square or even rectangular. The method may include overlapping adjacent sub-images during step (v) by

up to fifty percent of the length of the sub-image or up to seventy five percent of the area of the sub-image. This overlap in the sub-images processing steps increases the spatial resolution, measurement density, of the technique. An overlap greater than 50% introduces redundancy and unnecessary computational step but still may be used to smooth or average displacement measurements where calculation speed is non-critical.

The method may include providing the imaging means in a form including a microscope, typically having a numerical aperture of between about 0.1 to about 0.5. Thus, the method allows the use of high numerical aperture (NA) imaging systems as the tiny depth of focus at high NA can be compensated. The method may include providing the imaging means in a form including an objective lens typically having between about x5 and about x50 magnification. The method may include providing the imaging means in a form including a charge coupled device (CCD).

The method may include providing the imaging means in the form of an ultrasound transducer.

The method may include outputting at least one of the following to an output device: a strain map, a deformation map, a numerical measure of deformation, typically in a distance perpendicular to a nominal horizontal plane of the sample. The method may further include providing the output device in the form of one of the following: a visual display unit (VDU), a printer, and a computer readable medium.

The method may include measuring deformations in the (xy) plane to sub-pixel resolution, typically 0.1 to 0.01 of a pixel.

According to a second aspect of the present invention there is provided an image analysis apparatus comprising imaging means arranged to capture a image of at least part of a sample, processing means arranged to process the image and drive means arranged to effect relative motion between the sample and the imaging means characterised in that the imaging means is arranged to capture at least two images of a part of the sample at at least two focal planes, relative movement between the sample and the imaging means being effected by the drive means the processing means being arranged to determine a correlation of each of said images with a reference and to select one of the at least two images upon the basis of said correlation, and the processing means being further arranged to determine a displacement, if any, of at least one feature within said part of the sample.

This apparatus provides a measure of image focus for each area of the sample, typically by dividing each image into sub-images and comparing them to the reference. Thus, curvature of the sample can be compensated for and measured far more accurately than in prior art arrangements where a single focal plane is assumed across the sample. Additionally, the use of an individual focal plane for each sub-image reduces errors in xy plane deformation measurement as errors associated with poor focussing are reduced.

The processing means may be arranged to select a best focus sub-image, typically having the highest correlation with said respective reference. This produces a composite best focus image thus minimising focussing errors in (xy) deformation measurement.

Each reference may be a image either from an image having a single focal plane, or selected from a plurality of sub-images captured at a plurality of

focal planes or from a composite image where a plurality of sub-images define at least two localised focal planes.

5 The imaging means may be arranged to capture a plurality of images centred about a best focus focal plane of the imaging means when the sample is an undeformed state. The drive means may be arranged to effect relative motion between the imaging means and the sample in steps of substantially equal distance.

10 The imaging means may include a charge coupled device (CCD) camera, typically with an imaging array of between 640x480 and 1024x1024 pixels. The imaging means may include a microscope, such a microscope typically having an objective of about x5, about x50 or greater. The microscope may have a numerical aperture of between about 0.1 to about
15 0.5, often about 0.25 or above.

The imaging means may be an ultrasound transducer. The drive means may be arranged to sweep the transducer over a sample. The processing means may be arranged to decorrelate images to remove palpitation of
20 soft tissues, for example muscle and/or fat. This allows the extent (e.g. size) of hard tissue, for example a tumour or a bone, to be ascertained more accurately than is currently the case as soft tissue effects can be removed from the image by the processing means.

25 The processing means may be a personal computer (PC) or other computing device, for example a workstation. The processing means may be arranged to divide each image into sub-images of between 16 x 16 and 64 x 64 pixels, typical sub-images sizes are 24 x 24 or 32 x 32 pixels. The processing means may be arranged to overlap sub-images boundaries
30 by up to fifty percent of the size of the sub-images.

The processing means may be arranged to generate a strain map, or a deformation map of the sample which is typically output via an output means, for example a printer, visual display unit (VDU) or a file on a computer readable medium.

5

According to a third aspect of the present invention there is provided a data structure encoded upon a computer readable medium the data structure including:

- a first entry corresponding to a data set indicative of a part of a sample in
- 10 a first state; characterised in that:
 - a plurality of secondary entries corresponding to at least two inputs received from an imaging means of said part of the sample in a second state;
 - the first entry and the at least two of second entries are arranged to be
 - 15 operated upon by processing means to derive respective subsets of data; and
 - corresponding subsets of data derived from the first entry and the at least two of second entries are arranged to be operated upon by the processing means to determine a match therebetween.

20

- The first entry may be an image data file, for example in the form of a GIF, JPEG, TIFF or other suitable image data format. The first entry may be a computer generated model of the sample. The plurality of second entries may be image data files, for example in the form of a GIF,
- 25 JPEG, TIFF or other suitable image data format.

- The subsets of data may be indicative of region of the sample, which may be imaged by the imaging means. The first entry and the plurality of second entries may be arranged to be operated upon by the processing
- 30 means to determine a best match therebetween.

The second entries may correspond to at least two image data sets obtained at differing focal planes of an imaging means.

5 The subsets of data files may be arranged to be operated upon by the processing means by the execution of a correlation technique, a fringe projection technique or a spectrum suppression technique thereupon.

10 According to a fourth aspect of the present invention there is provided a method of assessing the conformance of an electronic device with an accepted standard comprising the method according to the first aspect of the present invention.

The method may comprise providing the accepted standard in the form of a reference, which may be computer generated or physical.

15

The electronic device may be a discrete component, an integrated circuit or a packaged device.

20 According to a fifth aspect of the present invention there is provided an electronic device assessment apparatus according to the second aspect of the present invention.

25 According to a sixth aspect of the present invention there is provided a method of manufacture of an electronic device comprising the method according to the first aspect of the present invention.

30 According to a seventh aspect of the present invention there is provided an electronic device, the manufacture of which included the use of the method according to the first aspect of the present invention or the apparatus according to the second aspect of the present invention.

According to an eighth aspect of the present invention there is provided a computer readable medium having stored thereupon instructions for causing an apparatus to execute the method according to the first aspect of the present invention.

5

According to a ninth aspect of the present invention there is provided a program storage device readable by an apparatus and encoding a program of instructions which when operated upon the apparatus cause the apparatus to operate as the apparatus according to the second aspect of the present invention.

10

According to a tenth aspect of the present invention there is provided computer software which run on an apparatus causes a processing means of the apparatus to generate a data set indicative of an initial image of a sample in said first state and further causes the processing means to produce a plurality of data sub-sets indicative of regions of the sample from said data set, the software being characterised by:

15

causing imaging means to capture a plurality of secondary images of the sample in said second state at least two focal planes and causing the processing means to produce a plurality of sub-images corresponding substantially in location to the regions of the sample defined by the data sub-sets from each of the plurality of secondary images and subsequently causing the processing means to correlate at least one of the data sub-sets with each corresponding one of the plurality of secondary sub-images using processing means, selecting one of the secondary sub-images for each data sub-set based upon said correlation and determining a displacement, if any, of at least one feature within the sub-image.

20

25

According to a eleventh aspect of the present invention there is provided a method of improving the accuracy of in-plane measurement of movement of a feature by compensating for out-of-plane movement of the feature.

- 5 The method may include removing decorrelation in the xy plane due to said out of plane movement.

According to a twelfth aspect of the present invention there is provided a computer arranged to have running upon it software according to the tenth
10 aspect of the present invention and/or have the data structure according to the third aspect of the present invention and/or execute the method according to the first aspect of the present invention.

According to a thirteenth aspect of the present invention there is provided
15 a method of diagnosis of a patient's condition comprising the steps of:

- i) palpating a region of soft tissue having a region of hard tissue therein;
- ii) capturing a plurality of ultrasound images spaced along said region of soft tissue;
- 20 iii) processing the images so as to produce sub-images therefrom;
- iv) deriving a strain map of the region of hard tissue;
- v) repeating steps (i) to (iv) at a different time;
- vi) comparing the strain maps derived in steps (iv) and (v); and
- vii) determining if the region of hard tissue has varied in size in the
25 time interval between steps (iv) and (v) from the comparison of step (vi).

The method may include changing, varying or altering the dose of a medicament prescribed to the patient in response to the result of step (vii). Alternatively, the method may include changing a medicament
30 prescribed to the patient in response to the result of step (vii).

The method may include producing a three dimensional profile of the region of hard tissue from the strain maps derived in steps (iv) and (v). The method may include imaging the change in size of the region of hard tissue using the method of the first aspect of the present invention.

5

The hard tissue may be any at least one of the following: bone, a tumour (e.g. cancerous cells), a bio-compatible matrix having cells growing thereupon.

10 According to a fourteenth aspect of the present invention there is provided a method of treatment of a patient's condition comprising the steps of:

- i) palpating a region of soft tissue having a region of hard tissue therein;
- 15 ii) capturing a plurality of ultrasound images spaced along said region of soft tissue;
- iii) processing the images so as to produce sub-images therefrom;
- iv) deriving a strain map of the region of hard tissue;
- v) repeating steps (i) to (iv) at a different time;
- 20 vi) comparing the strain maps derived in steps (iv) and (v);
- vii) determining if the region of hard tissue has varied in size in the time interval between steps (iv) and (v) from the comparison of step (vi); and at least one of;
- viii) altering the dose of a medicament prescribed to the patient in
- 25 response to the result of step (vii);
- ix) changing a medicament prescribed to the patient in response to the result of step (vii).

The hard tissue may be any at least one of the following: bone, a tumour
30 (e.g. cancerous cells), a bio-compatible matrix having cells growing thereupon.

The invention will now be described by way of example only, with reference to the accompanying drawings, in which:

5 **Figure 1** is a microscope imaging arrangement according to an aspect of the present invention;

Figure 2 is a schematic representation of an electronic package prior to deformation;

10

Figure 2a is a plan view of the package of **Figure 2** prior to deformation;

Figure 3 is a schematic representation of the package of **Figure 2** following deformation;

15

Figure 3a is a plan view of the package of **Figure 3**;

Figure 4 is a schematic representation of a stack of images captured by the imaging arrangement of **Figure 1**;

20

Figure 4a is a schematic representation of the formation of a composite initial image from a stack of images;

Figure 5 is a representation of an image of the device of **Figure 2** showing sub-image borders;

25

Figure 5a is a representation of a sample being focussed using a fringe projection method;

Figure 5b is a plot showing the effects of good and poor focussing on the magnitude of the Fourier component corresponding to the spatial frequency of the fringes shown in Figure 5a;

- 5 Figure 6 is a vector displacement map of the device of Figure 3 generated using the arrangement of Figure 1;

Figure 7 is an ultrasound transducer, in use imaging hard tissue embedded in soft tissue in accordance with at least one aspect of the
10 present invention;

Figure 8 is a flow chart detailing a method of deformation measurement; and

- 15 Figure 9 is a computer readable medium according to an aspect of the present invention.

Referring now to Figure 1 a microscope imaging arrangement 100 comprises a microscope body 102 that houses an objective lens 104, a
20 CCD array camera 106, a drive mechanism 108 and a sample stage 110.

The camera 106 is connected to a PC 112, which comprises a processor unit 114, a VDU 116, a keyboard 118 and a mouse 120. The processor unit 114 receives images from the camera 106 and controls the drive
25 mechanism 108 such that the drive mechanism 108 effects relative motion between the lens 104 and the stage 110. The stage 110 is shown with an electronic device package 122 mounted thereupon. The device 122 has structures 124a-c projecting from a surface adjacent the lens 104.

- 30 In one embodiment of the present invention a plurality of primary images, usually micrographs, of part of the package 122 are captured using the

lens 104 and camera 106 at a number of differing focal planes. The best focus primary image is selected using techniques described hereinafter. The lens 104 typically has a magnification of x5 to x50 and a numerical aperture of between 0.1 and 0.5, usually 0.25. The camera 106 typically
5 includes an (640x480) or (1024x1024) active pixel array, usually measuring 6mm x 8mm.

The initial image is transmitted to the processor unit 114 and can be displayed upon the VDU 116 should a user wish to view it. The
10 processor unit 114 divides the initial image into sub-images. These sub-images are usually 24 x 24 pixels, or 32 x 32 pixels, in size.

The package 122 is deformed typically by thermal cycling or mechanical stressing. The deformation can be achieved by in-situ heating or stressing
15 on the stage 110 or by ex-situ heating or stressing.

Figure 2 shows the package 122 in its undeformed state. The package 122 comprises a substrate 202 having contact pins 204 a-d projecting therefrom. In the case of flip chip technologies the contact
20 pins 204 a-d will be replaced by solder balls attached to metallisation on a lower surface of the substrate 202. The substrate 202 has active devices 206, 208, 210 mounted thereupon such as, for example random access memory (RAM), a central processor unit (CPU), a frequency synthesiser or an arithmetic logic unit (ALU) or any other suitable device.

25 Figure 2a is a plan view of the package 122 prior to deformation.

Figure 3 shows the package 122 following deformation, such as heating, mechanical stressing or a combination of both. The substrate 202 has buckled, resulting in both lateral and vertical displacements of the
30 devices 206-210. An inaccurate measurement of the lateral displacements of the devices 206-210 can be achieved by use of the known techniques

described hereinbefore subject to their limitations for example due to focussing errors. However, the measurement of vertical displacements is not readily achievable using the prior art methods, and moreover vertical displacements introduce decorrelation when comparing in-plane
5 measurements of sub-image features. Referring to Figure 3a, the lateral displacement of the devices 206-210 can be seen relative to their locations in Figure 2a. As can be seen the true 'total' deformation of the package 122 is larger than that suggested by just the in-plane deformation as this neglects the out-of-plane deformation of the package 122.

10

Referring now to Figure 1, once a best focus focal plane for imaging part of the undeformed package 122 has been established, and the package 122 is deformed, the drive mechanism 108 moves the microscope body 102 and the CCD camera 106 such that the focal plane of the objective 104
15 lies below the focal plane established for the undeformed package 122. It will be appreciated that it may be the stage 110 that is moved and not the microscope body 102.

An image is captured by the camera 106 at the new objective - package
20 distance. The drive mechanism 108 then moves the microscope body 102 and camera 106 to a new position closer to the undeformed package's focal plane. Another image is captured at the new position by the camera 106. This sequence of movement of the focal plane of the microscope arrangement 100 and image capture continues through the
25 focal plane established for the undeformed package and away from the upper surface of the package.

The movement of the microscope body 102 will usually be incremented step wise with a pitch Δ , where Δ is typically $\frac{1}{(20 \times NA^2)}$, such that a stack of $2p+1$ 'through focus' images are captured, where p determined by an expected amount of out-of-plane deformation. The number of steps,

- 2p+1, depends upon the sample profile but is typically between 21 and 61. This is shown in Figure 4 in which an image 400 constitutes the image captured at the focal plane established for the part of undeformed package imaged in the primary image. Secondary images 404a-c are the images captured above the image 400. Each of the secondary images 400, 402a-c, 404a-c are separated from their adjacent image by a step size Δ . Thus, in this instance a total depth of 6Δ is scanned through the image 400 and centred thereupon.
- 10 It will be appreciated that although the stack of images is shown centred upon the image 400 taken at the focal plane established for the undeformed package this need not be the case. An asymmetric distribution of images captured about the image 400 may be appropriate in the case of an expected asymmetric deformation of the package 122.
- 15 In order to obtain stepwise relative motion between the stage 110 and the microscope body 102 the drive mechanism 108 will usually take the form of a stepper motor or a servomotor.
- The processing unit 114 divides each of the images 400-404c into a plurality sub-images. If the image of the undeformed package is divided into an (mxn) array so are the images 400-404c, this is shown in Figure 5 by the dashed lines. In this instance the image 500 is divided into a (5x4) matrix of sub-images 502a-t. As can be seen from Figure 5 the two uppermost 502a,e,i,m,q-502b,f,j,n,r and the two most extreme left columns of sub-images 502a,b,c,d -502e,f,g,h overlap, in this case by approximately 25%. The overlap of images reduces the complexity and computational load of subsequent image processing steps by allowing averaging within the overlapping region. A practical upper limit upon the degree of overlapping is 50% of adjoining cells. It will be appreciated that adjacent sub-images may not overlap or may only overlap by a small amount.

Referring now to Figure 4a a plurality of initial images 410a-g of the undeformed package 122 are captured at varying focal planes as hereinbefore described in relation to the deformed package 122. The
5 initial images 410a-g are divided into respective pluralities of sub-images and the best focus sub-image 412a-e for each region of the package 122 is selected using either the fringe projection method or the spectrum suppression method as detailed hereinafter. Thus, a composite "best focus" initial image 414 is produced. This "best focus" initial image 414
10 is then compared the secondary sub-images 502a-t as detailed hereinafter and out-of-plane deformation are determined with reference to individual focal planes of the initial sub-images.

The sub-images of each of the (mxn) columns are compared to sub-images
15 of the primary image of part of the undeformed package 122 in order to determine the sub-image that provides the best post deformation focus for that area of the package 122 using techniques that are described hereinafter. Thus, a composite "best-focus" image can be constructed from the best focus sub-images. This composite "best-focus" image can,
20 and usually will, contain sub-images obtained at different focal planes, i.e. at different heights relative to each other. This arrangement reduces errors in the determination of in-plane deformation over current systems due to an increase in the sharpness of focus of the present invention reduces these errors.

25 Additionally, by ascertaining which of the stack of sub-images constitutes the best-focus image it is possible to determine the amount of out-of-plane deformation occurring at an area of the package 122, i.e. if it is the n^{th} sub-image that is the best focus sub-image the vertical displacement
30 is $\pm n \Delta$.

A brief description of three techniques for determining the best focal position of a sub-image that can be readily incorporated into a conventional bright field microscope follows hereinafter.

5 1. **Fringe projection method:** with this method an intensity grating is inserted in a field stop plane of the microscope 102. This causes a set of optical fringes to be projected onto the sample surface along the optical axis of the microscope. Defocusing of the sub-image will cause fringe contrast to decrease. This can be measured by taking the Fourier
10 transform of the sub-image, and monitoring the amplitude of the Fourier component corresponding to the fringe frequency. The sub-image with the largest Fourier component corresponding to the fringe frequency is the best focus sub-image. Figure 5a shows the sample 122 having fringes 504a-e of a known spatial frequency projected upon it. Figure 5b shows
15 the effect of poor focus (plot A) and good focus (plot B) upon the magnitude of the Fourier component corresponding to the fringes spatial frequency.

2. **Spectrum suppression method:** with this method, a Fourier
20 transform is taken of each sub-image. It is well known that one effect of defocusing the sample is the attenuation of a sample frequency spectrum. In practice the attenuation in the mid-spatial frequency range provides the best measure typically between 0.25 and 0.5 of the optical transfer cut-off frequency defined by the lens NA. By monitoring the amplitudes of the
25 frequency components near this range, the best focus position of the sub-image can be determined by selecting the sub-image with the largest mid-spatial frequency amplitudes, for example the contacts 204a-d. The effect of poor focussing compared to good focussing upon the magnitude of the Fourier component corresponding to the selected frequency is the
30 similar to that shown in Figure 5b.

3. **Correlation method:** with this method a two dimensional correlation is taken between each deformed sub-image and the corresponding undeformed, sub-image. Defocused sub-images will result in correlation functions with reduced peak value. Thus the correlation function with the highest peak will correspond to the in focus sub-image, i.e. match each (possibly the best focussed) initial sub-image with the best correlated of the equivalent secondary sub-images. This method gives optimal results in determining the position of displaced objects (e.g. component identification and positioning in manufacturing) but may give ambiguous results on deformed objects. 1D-correlation is also possible and has been applied to ultrasound.

Of the methods, the first one is potentially most accurate. It is also suitable for surfaces with sparse features. The advantage of the other two methods is that no additional optical component is required.

Techniques such as curve fitting can be applied to all three methods, to improve the sensitivity of the measurements.

Referring now to Figure 6, a strain map 600 of the deformed device 122 is composed of best focus sub-images. Each of the best focus sub-images may not and indeed probably will not correspond to the same distance away from the focal plane established for the undeformed device 122. By utilising the best focus sub-images the strains at various points on the surface can be accurately calculated, typically with an accuracy of 0.1 to 0.01 pixels. In Figure 6 the calculated strains are represented as vector arrows 604 although they could alternatively be represented as numerical values, a greyscale or a colour scale, or any other suitable way of differentiating between regions of differing strain.

Referring now to Figure 7, an ultrasound imaging arrangement 700 comprises an ultrasound transducer 702 that is in communication with a PC 704, or other suitable processing device.

- 5 The transducer 702 is placed against a patient, shown as an arm 706 in this instance and soft tissue 708, such as muscle or fat, surrounding hard tissue 710, for example bone is palpitated. Ultrasound images are acquired along the arm 706 during the palpitation, so as to form a stack of images 712a-e. The soft tissue 708 under palpitation appears as a mass
10 having uniform strain therein and the hard tissue 710 appears as a region having non-uniform strain. The stack of ultrasound images are processed in a similar manner as hereinbefore described in relation to optical images. Due to the difference in the distribution of the strains within the soft tissue 708 and the hard tissue 710 the strains within the hard
15 tissue 710 can be measured and imaged, as can the extent of the hard tissue 710.

It will be appreciated that although shown as a bone the hard tissue may be any tissue that is significantly more solid than the surrounding tissues,
20 for example tumour tissue surrounded in fat or muscle such as a breast tumour.

When images of an area of interest of a patient are recorded using the imaging arrangement 700 are temporally separated it is possible to
25 determine the rate of change of size of the hard tissue 710 by a comparison of the images and/or strain maps generated. For example this technique allows the rate of growth/reduction of a tumour, the rate of knitting of a broken bone or the rate of migration of biological materials, e.g. cells, into a bio-compatible supporting matrix to be determined.

Referring now to Figure 8 this is a flowchart of a method of deformation analysis according to the present invention in which a plurality of primary images of a sample in an undeformed state are captured at a plurality of focal planes, using an imaging device, typically along an optical axis of the device (step 800).

Subsequently a plurality of primary sub-images are produced from these primary images by a processor (step 802). A best focus primary sub-image is determined for each area within the primary image (Step 803).

10

A plurality of secondary images of the sample in its deformed state are captured by the imaging device, typically, at various points along the imaging devices optical axis (Step 804). Each secondary image is divided into a plurality of sub-images each having a position that substantially corresponds to the sub-images formed from the initial image (step 806). The best focus secondary sub-image for each initial sub-image is determined (step 807). The best focus primary sub-images are correlated with each corresponding best focus secondary sub-images using a processor (step 808).

20

Referring now to Figure 9, this shows a computer readable medium 900, for example a magnetic disc, an optical disc, a CD-rom, or a DVD, having software encoded thereupon suitable for causing an apparatus to execute the method outlined in relation to Figure 8.

25

CLAIMS

1. An image analysis method comprising the steps of:
 - 5 i) capturing at least two primary images of at least one part of a sample (122) in a first state using imaging means (102), the at least two primary images being captured at different focal planes;
 - ii) capturing at least two secondary images of said at least one part of said sample (122) in a second state using imaging means (102), the
10 at least two secondary images being captured at differing focal planes;
 - iii) selecting one of said primary images that has the best definition of at least one feature therein using processing means (114);
 - iv) selecting one of said secondary images which has the best
15 definition of said at least one feature therein using processing means (114); and
 - v) comparing the primary and secondary images selected in steps (iii); and (iv) in order to determine the displacement, if any, of a feature within said part of said sample (122).
20
2. The method of claim 1 including providing the imaging means (102) in a form including a microscope (102) or in a form including an ultrasound transducer (702).
- 25 3. The method of either of claims 1 or 2 including determining a best focus sub-image from the plurality of second plurality of images in step (iv).
4. The method of any preceding claim including measuring an out-of-
30 plane displacement of at least one feature by multiplying a number of

steps moved by the imaging means in achieving a desired secondary image quality by the step size.

- 5 5. The method of any preceding claim including providing primary image in the form of an initial image captured by the imaging means (102) having a single nominal focal plane depth or in the form of a composite image (410) composed of sub-images (412a-412e) each defining a focal plane depth.
- 10 6. The method of any preceding claim including outputting at least one of the following to an output device: a strain map (600), a deformation map, a numerical measure of deformation.
- 15 7. The method of any preceding claim including measuring a deformation of the sample (122) in the (xy) plane to a sub-pixel resolution of at least 0.1 pixels.
- 20 8. An image analysis apparatus (100) comprising imaging means (102) arranged to capture an image of at least part of a sample (122), processing means (114) arranged to process the image and drive means (108) arranged to effect relative motion between the sample (122) and the imaging means (102) characterised in that the imaging means (102) is arranged to capture at least two images (404a-c) of a part of the sample (122) at at least two focal planes, relative movement
25 between the sample (122) and the imaging means (102) being effected by the drive means (108) the processing means (114) being arranged to determine a correlation of each of said images (404a-c) with a reference and to select one of the at least two images (404a-c) upon the basis of said correlation, and the processing means (114) being further arranged to
30 determine a displacement, if any, of at least one feature within said part of the sample (122).

9. Apparatus according to claim 8 further characterised by the imaging means including a microscope (102) or an ultrasound transducer (702).
- 5 10. Apparatus according to either of claims 8 or 9 further characterised by the processing means (114) being arranged to select a best focus sub-image from the at least two images.
- 10 11. Apparatus according to any one of claims 8 to 10 further characterised by the reference being a primary image either from an image having a nominal single focal plane or a sub-image (412a-412e) from a composite primary image (410) where each sub-image (412a-412e) defines a localised focal plane.
- 15 12. A data structure encoded upon a computer readable medium (900) the data structure including:
a first entry corresponding to a data set indicative of part of a sample (122) in a first state; characterised in that:
a plurality of secondary entries corresponding to at least two inputs
20 received from an imaging means (102), of said part of the sample (122) in a second state;
the first entry and the at least two second entries are arranged to be operated upon by processing means (114) to derive respective subsets of data; and
25 corresponding subsets of data derived from the first entry and the at least two second entries are arranged to be operated upon by the processing means (114) to determine a match therebetween.
- 30 13. A data structure according to claim 12 further characterised by the first entry and the plurality of secondary entries being image data files.

14. A data structure according to claim 13 further characterised by the subsets of data being sub-image data files, which are portions of an area imaged by the imaging means (102).

5 15. A data structure according to any one of claims 12 to 14 further characterised by the subsets of data files being arranged to be operated upon by the processing means by the execution of a correlation technique, a fringe projection technique or a spectrum suppression technique thereupon.

10

16. A data structure according to any one of claims 12 to 15 further characterised by the second entries corresponding to at least two image data sets obtained at differing focal planes.

15 17. Computer software which run on an apparatus causes a processing means of the apparatus to generate a data set indicative of an initial image of a sample in said first state and further causes the processing means to produce a plurality of data sub-sets indicative of regions of the sample from said data set, the software being characterised by:

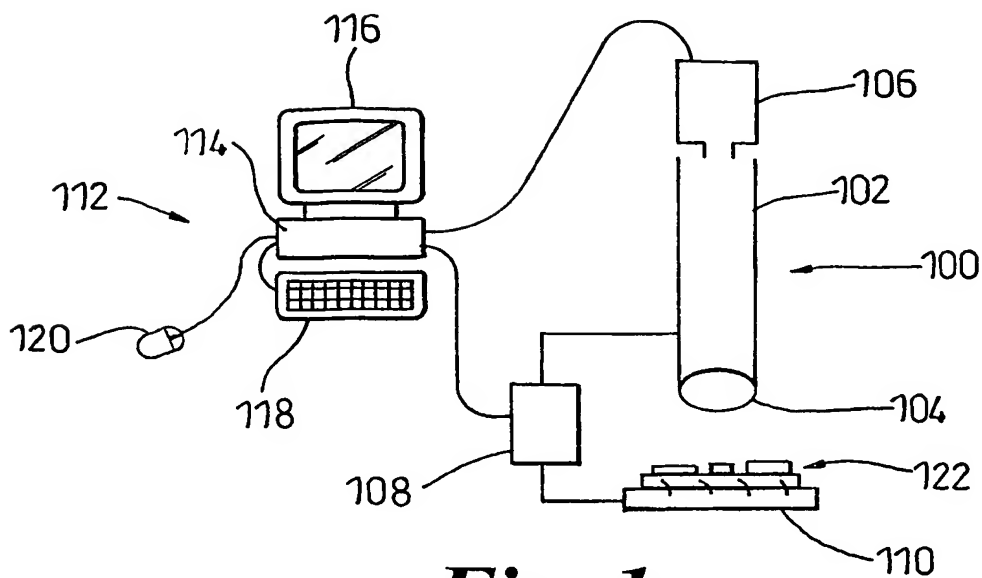
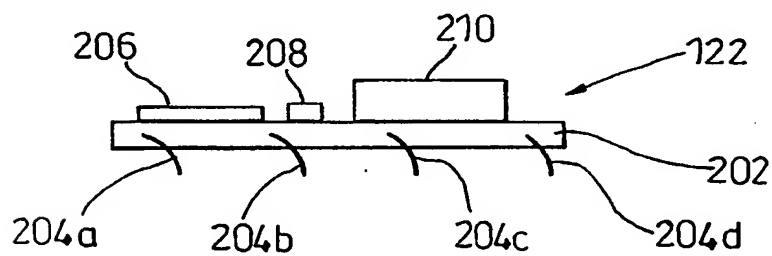
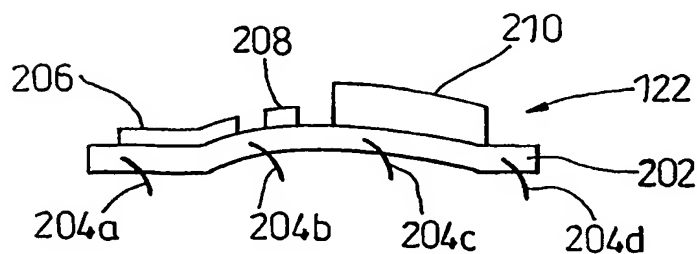
20 causing imaging means to capture a plurality of secondary images of the sample in said second state at at least two of focal planes and causing the processing means to produce a plurality of sub-images corresponding substantially in location to the regions of the sample defined by the data sub-sets from each of the plurality of secondary images and subsequently
25 causing the processing means to correlate at least one of the data sub-sets with each corresponding one of the plurality of secondary sub-images using processing means selecting one of the secondary sub-images for each data sub-set based upon said correlation and determining a displacement, if any, of least one feature within the sub-image.

30

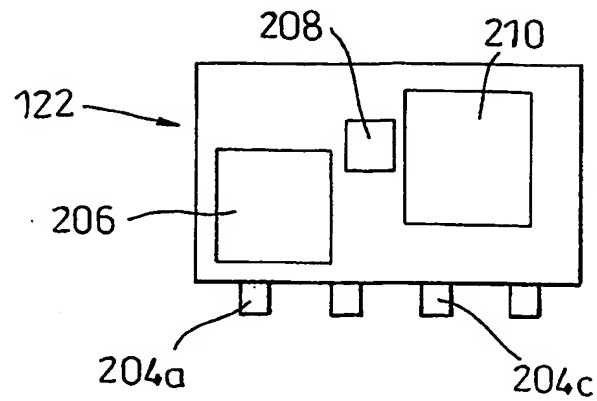
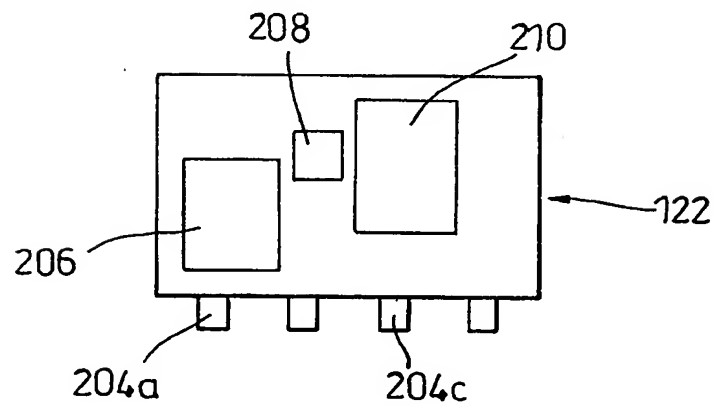
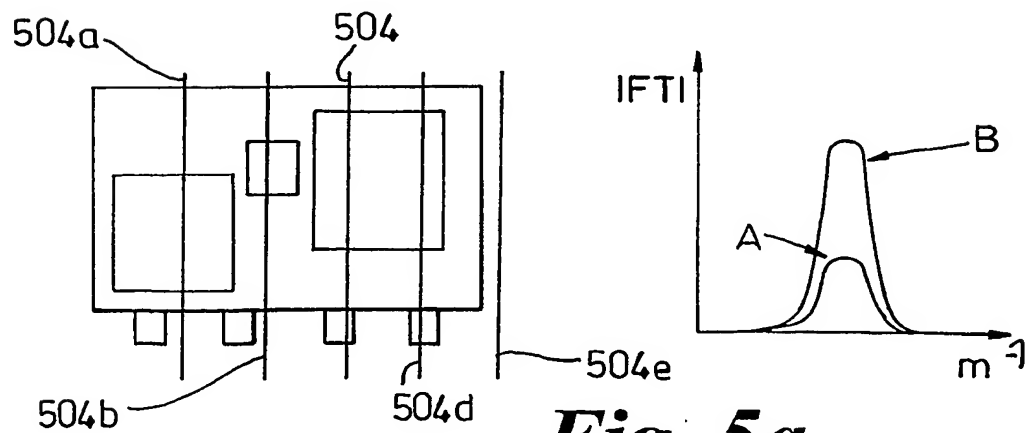
ABSTRACT

An image analysis apparatus comprises a microscope (102) arranged to capture an image of a sample (122), a processor unit (114) arranged to process the image and a drive mechanism (108). The drive mechanism (108) varies the distance between the sample (122) and the microscope (102) along the optical axis of the microscope (102). The microscope (102) is arranged to capture a plurality of images (402a-404c) of the sample (122) at a plurality of focal planes (distances), along the optical axis. This is done for the sample in a first state and for the sample being in a second state (e.g. before and after deformation of the object). The processor unit (114) is arranged to divide each of the plurality of captured images (402a-404c) into a plurality of sub-images and select one of each of the plurality of sub-images having the best focus characteristics. Both sets of sub-images are compared to determine in-plane and out-of-plane deformations.

1/6

**Fig. 1****Fig. 2****Fig. 3**

2/6

*Fig. 2a**Fig. 3a**Fig. 5a*

3/6

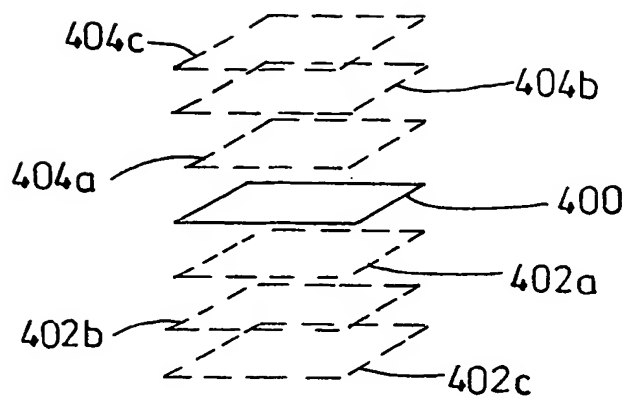


Fig. 4

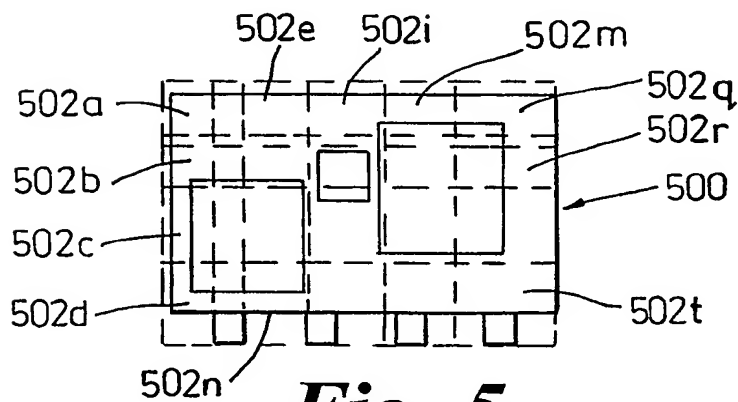


Fig. 5

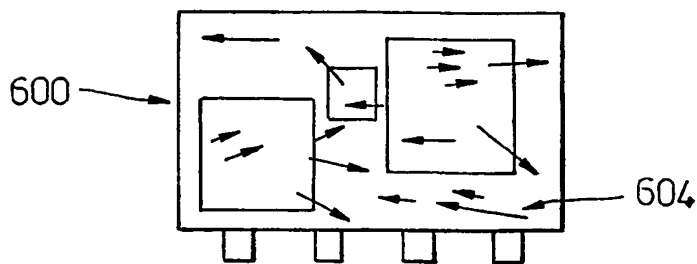


Fig. 6

4/6

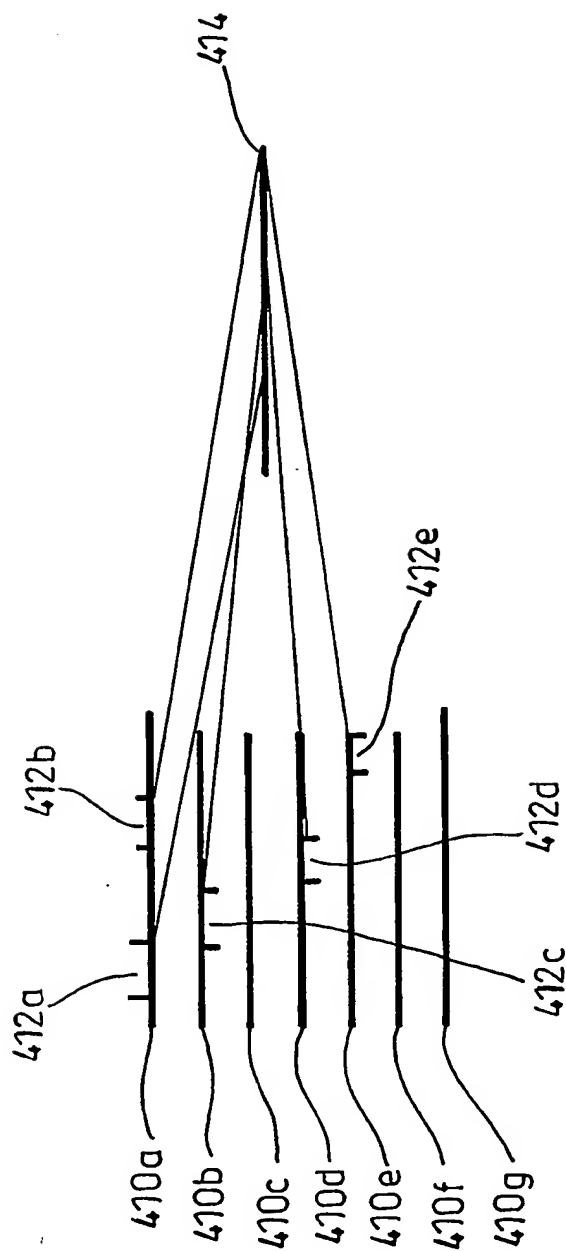


Fig. 4a

5/6

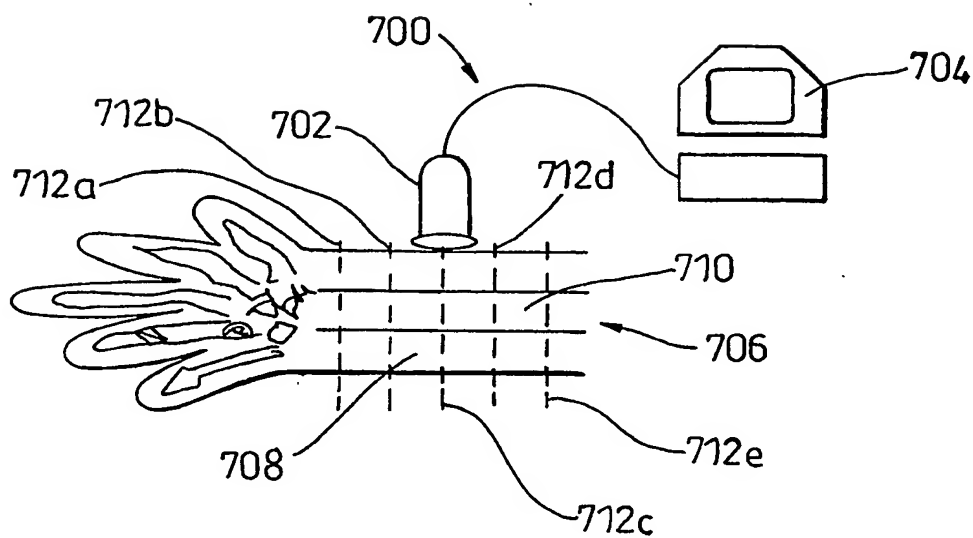


Fig. 7

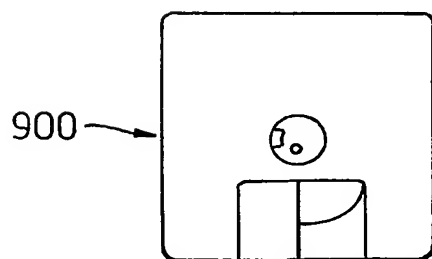
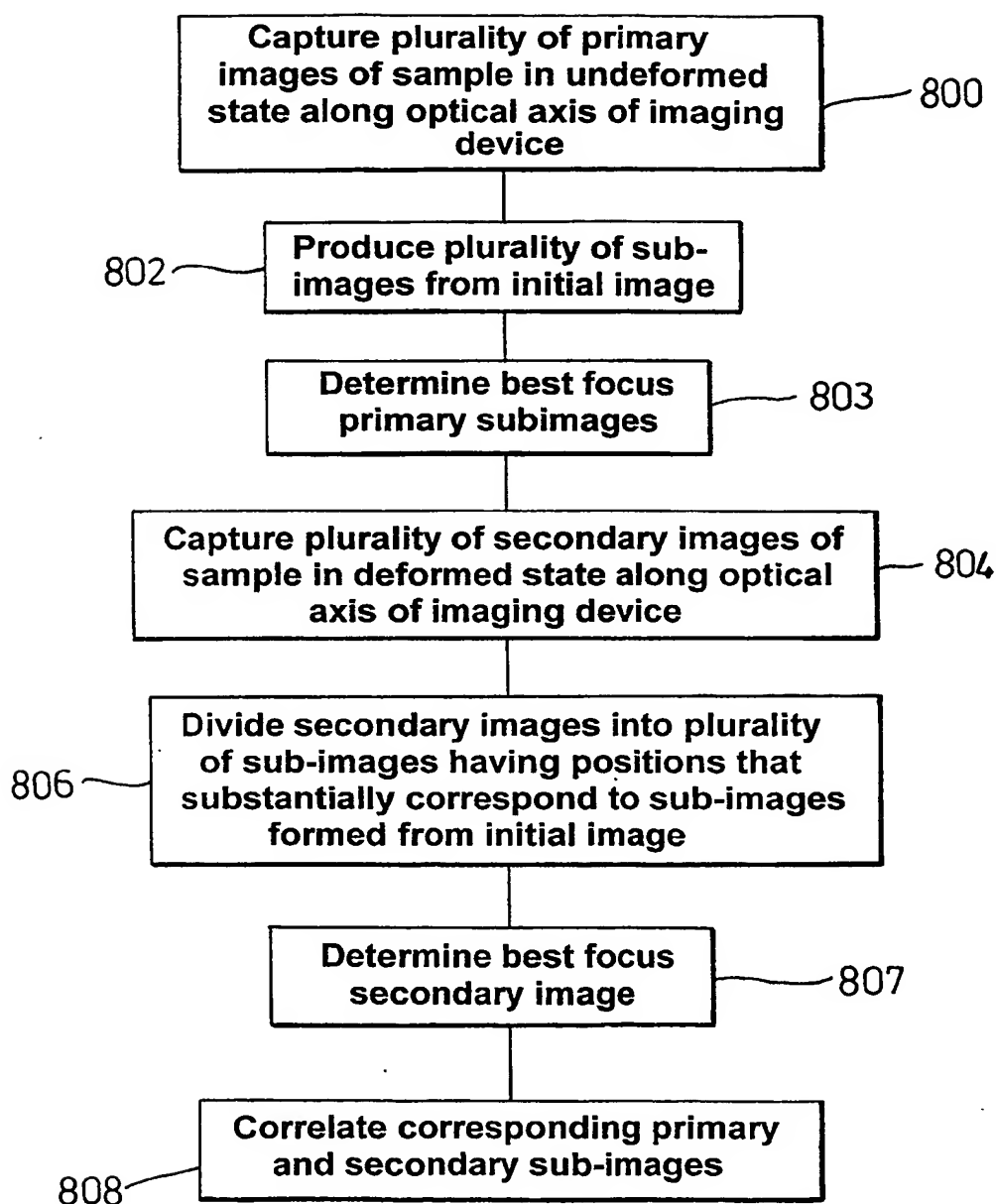


Fig. 9

6/6

*Fig. 8*

PATENT COOPERATION TREATY

From the INTERNATIONAL SEARCHING AUTHORITY

PCT

NOTIFICATION OF TRANSMITTAL OF THE INTERNATIONAL SEARCH REPORT OR THE DECLARATION

(PCT Rule 44.1)

To:
BARKER BRETELL
138 Hagley Road
Edgbaston
Birmingham B16 9PW
UNITED KINGDOM

Date of mailing
(day/month/year) 11/06/2004

Applicant's or agent's file reference
JL3856

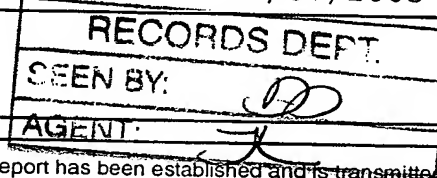
FOR FURTHER ACTION See paragraphs 1 and 4 below

International application No.
PCT/GB 03/03052

International filing date
(day/month/year) 14/07/2003

Applicant

THE UNIVERSITY OF NOTTINGHAM



1. ☒ The applicant is hereby notified that the International Search Report has been established and is transmitted herewith.

Filing of amendments and statement under Article 19:

The applicant is entitled, if he so wishes, to amend the claims of the International Application (see Rule 46):

When? The time limit for filing such amendments is normally 2 months from the date of transmittal of the International Search Report; however, for more details, see the notes on the accompanying sheet.

Where? Directly to the International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Fascimile No.: (41-22) 740.14.35

For more detailed instructions, see the notes on the accompanying sheet.




2. ☐ The applicant is hereby notified that no International Search Report will be established and that the declaration under Article 17(2)(a) to that effect is transmitted herewith.
3. ☐ **With regard to the protest** against payment of (an) additional fee(s) under Rule 40.2, the applicant is notified that:
- ☐ the protest together with the decision thereon has been transmitted to the International Bureau together with the applicant's request to forward the texts of both the protest and the decision thereon to the designated Offices.
- ☐ no decision has been made yet on the protest; the applicant will be notified as soon as a decision is made.

4. **Further action(s):** The applicant is reminded of the following:

Shortly after **18 months** from the priority date, the international application will be published by the International Bureau. If the applicant wishes to avoid or postpone publication, a notice of withdrawal of the international application, or of the priority claim, must reach the International Bureau as provided in Rules 90bis.1 and 90bis.3, respectively, before the completion of the technical preparations for international publication.

Within **19 months** from the priority date, a demand for international preliminary examination must be filed if the applicant wishes to postpone the entry into the national phase until 30 months from the priority date (in some Offices even later).

Within **20 months** from the priority date, the applicant must perform the prescribed acts for entry into the national phase before all designated Offices which have not been elected in the demand or in a later election within 19 months from the priority date or could not be elected because they are not bound by Chapter II.

Name and mailing address of the International Searching Authority
 European Patent Office, P.B. 5818 Patentlaan 2
NL-2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer
Raoul Emme

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference JL3856	FOR FURTHER ACTION see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 03/03052	International filing date (day/month/year) 14/07/2003	(Earliest) Priority Date (day/month/year) 18/07/2002
Applicant THE UNIVERSITY OF NOTTINGHAM		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 5 sheets.

☒ It is also accompanied by a copy of each prior art document cited in this report.

1. Basis of the report

- a. With regard to the language, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

- b. With regard to any nucleotide and/or amino acid sequence disclosed in the international application, the international search was carried out on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. ☐ Certain claims were found unsearchable (See Box I).

3. ☐ Unity of invention is lacking (see Box II).

4. With regard to the title,

☐ the text is approved as submitted by the applicant.

☒ the text has been established by this Authority to read as follows:

MEASURING 3D DEFORMATIONS OF AN OBJECT BY COMPARING FOCUSING CONDITIONS FOR SHARP CAPTURING OF SAID OBJECT BEFORE AND AFTER DEFORMATION

5. With regard to the abstract,

☐ the text is approved as submitted by the applicant.

☒ the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the drawings to be published with the abstract is Figure No.

☐ as suggested by the applicant.

☐ because the applicant failed to suggest a figure.

☒ because this figure better characterizes the invention.

8

☐ None of the figures.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/GB 03/03052

Box III TEXT OF THE ABSTRACT (Continuation of item 5 of the first sheet)

An image analysis apparatus comprises a microscope (102) arranged to capture an image of a sample (122), a processor unit (114) arranged to process the image and a drive mechanism (108). The drive mechanism (108) varies the distance between the sample (122) and the microscope (102) along the optical axis of the microscope (102). The microscope (102) is arranged to capture a plurality of images (402a-404c) of the sample (122) at a plurality of focal planes (distances), along the optical axis. This is done for the sample in a first state and for the sample being in a second state (e.g before and after deformation of the object). The processor unit (114) is arranged to divide each of the plurality of captured images (402a-404c) into a plurality of sub-images and select one of each of the plurality of sub-images having the best focus characteristics. Both sets of sub-images are compared to determine in-plane and out-of-plane deformations

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 03/03052

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06T7/60

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G06T G01B G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	VOGEL D ET AL: "Microdac - a novel approach to measure in situ deformation fields of microscopic scale" MICROELECTRON. RELIAB. (UK), MICROELECTRONICS AND RELIABILITY, NO. 11/12, vol. 36, 8 October 1996 (1996-10-08) - 1996, pages 1939-1942, XP010528058 figures 1-4	12-15
Y	abstract page 1939, paragraph 3 page 1940, section "Principles of MicroDac" --- -/--	1-3, 5-11, 16, 17

☒ Further documents are listed in the continuation of box C.☐ Patent family members are listed in annex.

* Special categories of cited documents:

A document defining the general state of the art which is not considered to be of particular relevance

E earlier document but published on or after the international filing date

L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

O document referring to an oral disclosure, use, exhibition or other means

P document published prior to the international filing date but later than the priority date claimed

T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

& document member of the same patent family

Date of the actual completion of the international search

1 June 2004

Date of mailing of the international search report

11/06/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Ellerbrock, T

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 03/03052

C.(Continuation) DOCUMENT CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	<p>ALLEGRO S ET AL: "Autofocus for automated microassembly under a microscope" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON IMAGE PROCESSING (ICIP) LAUSANNE, SEPT. 16 - 19, 1996, NEW YORK, IEEE, US, vol. 1, 16 September 1996 (1996-09-16), pages 677-680, XP010202748 ISBN: 0-7803-3259-8 page 677, left-hand column, paragraph 4 -page 678, left-hand column, last paragraph page 678, right-hand column, paragraph 3 - paragraph 4 page 678, right-hand column, paragraph 6 -page 679, left-hand column, paragraph 3 page 680, left-hand column, paragraph 3 ---</p>	<p>1-3, 5-11,16, 17</p>
A	<p>NAYAR S K ET AL: "SHAPE FROM FOCUS" IEEE TRANSACTIONS ON PATTERN ANALYSIS AND MACHINE INTELLIGENCE, IEEE INC. NEW YORK, US, vol. 16, no. 8, 1 August 1994 (1994-08-01), pages 824-831, XP000464936 ISSN: 0162-8828 figures 3,8,9 page 825, left-hand column, paragraph 3 -page 826, left-hand column, paragraph 2 page 827, left-hand column, paragraphs 2,4 section "VII Automatic shape from focus system" page 829 -page 831 ---</p>	<p>1-17</p>
A	<p>NOGUCHI M ET AL: "Microscopic shape from focus using active illumination" PATTERN RECOGNITION, 1994. VOL. 1 - CONFERENCE A: COMPUTER VISION & IMAGE PROCESSING., PROCEEDINGS OF THE 12TH IAPR INTERNATIONAL CONFERENCE ON JERUSALEM, ISRAEL 9-13 OCT. 1994, LOS ALAMITOS, CA, USA, IEEE COMPUT. SOC, 9 October 1994 (1994-10-09), pages 147-152, XP010215958 ISBN: 0-8186-6265-4 abstract ---</p> <p style="text-align: center;">-/--</p>	<p>1-17</p>

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 03/03052

C.(Continuation) DOCUMENT CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	<p>PITTER M C ET AL: "SUBPIXEL MICROSCOPIC DEFORMATION ANALYSIS USING CORRELATION AND ARTIFICIAL NEURAL NETWORKS" OPTICS EXPRESS, OPTICAL SOCIETY OF AMERICA, WASHINGTON, DC,, US, vol. 8, no. 6, 12 March 2001 (2001-03-12), pages 322-327, XP001166850 ISSN: 1094-4087 Abstract and Introduction -----</p>	1-17

NOTES TO FORM PCT/ISA/220

These Notes are intended to give the basic instructions concerning the filing of amendments under article 19. The notes are based on the requirements of the Patent Cooperation Treaty, the Regulations and the Administrative Instructions under that Treaty. In case of discrepancy between these Notes and those requirements, the latter are applicable. For more detailed information, see also the PCT Applicant's Guide, a publication of WIPO.

In these Notes, "Article", "Rule", and "Section" refer to the provisions of the PCT, the PCT Regulations and the PCT Administrative Instructions respectively.

INSTRUCTIONS CONCERNING AMENDMENTS UNDER ARTICLE 19

The applicant has, after having received the international search report, one opportunity to amend the claims of the international application. It should however be emphasized that, since all parts of the international application (claims, description and drawings) may be amended during the international preliminary examination procedure, there is usually no need to file amendments of the claims under Article 19 except where, e.g. the applicant wants the latter to be published for the purposes of provisional protection or has another reason for amending the claims before international publication. Furthermore, it should be emphasized that provisional protection is available in some States only.

What parts of the International application may be amended?

Under Article 19, only the claims may be amended.

During the international phase, the claims may also be amended (or further amended) under Article 34 before the International Preliminary Examining Authority. The description and drawings may only be amended under Article 34 before the International Examining Authority.

Upon entry into the national phase, all parts of the international application may be amended under Article 28 or, where applicable, Article 41.

When?

Within 2 months from the date of transmittal of the international search report or 16 months from the priority date, whichever time limit expires later. It should be noted, however, that the amendments will be considered as having been received on time if they are received by the International Bureau after the expiration of the applicable time limit but before the completion of the technical preparations for international publication (Rule 46.1).

Where not to file the amendments?

The amendments may only be filed with the International Bureau and not with the receiving Office or the International Searching Authority (Rule 46.2).

Where a demand for international preliminary examination has been/is filed, see below.

How?

Either by cancelling one or more entire claims, by adding one or more new claims or by amending the text of one or more of the claims as filed.

A replacement sheet must be submitted for each sheet of the claims which, on account of an amendment or amendments, differs from the sheet originally filed.

All the claims appearing on a replacement sheet must be numbered in Arabic numerals. Where a claim is cancelled, no renumbering of the other claims is required. In all cases where claims are renumbered, they must be renumbered consecutively (Administrative Instructions, Section 205(b)).

The amendments must be made in the language in which the international application is to be published.

What documents must/may accompany the amendments?

Letter (Section 205(b)):

The amendments must be submitted with a letter.

The letter will not be published with the international application and the amended claims. It should not be confused with the "Statement under Article 19(1)" (see below, under "Statement under Article 19(1)").

The letter must be in English or French, at the choice of the applicant. However, if the language of the international application is English, the letter must be in English; if the language of the international application is French, the letter must be in French.

NOTES TO FORM PCT/ISA/220 (continued)

The letter must indicate the differences between the claims as filed and the claims as amended. It must, in particular, indicate, in connection with each claim appearing in the international application (it being understood that identical indications concerning several claims may be grouped), whether

- (i) the claim is unchanged;
- (ii) the claim is cancelled;
- (iii) the claim is new;
- (iv) the claim replaces one or more claims as filed;
- (v) the claim is the result of the division of a claim as filed.

The following examples illustrate the manner in which amendments must be explained in the accompanying letter:

1. [Where originally there were 48 claims and after amendment of some claims there are 51]:
"Claims 1 to 29, 31, 32, 34, 35, 37 to 48 replaced by amended claims bearing the same numbers; claims 30, 33 and 36 unchanged; new claims 49 to 51 added."
2. [Where originally there were 15 claims and after amendment of all claims there are 11]:
"Claims 1 to 15 replaced by amended claims 1 to 11."
3. [Where originally there were 14 claims and the amendments consist in cancelling some claims and in adding new claims]:
"Claims 1 to 6 and 14 unchanged; claims 7 to 13 cancelled; new claims 15, 16 and 17 added." or
"Claims 7 to 13 cancelled; new claims 15, 16 and 17 added; all other claims unchanged."
4. [Where various kinds of amendments are made]:
"Claims 1-10 unchanged; claims 11 to 13, 18 and 19 cancelled; claims 14, 15 and 16 replaced by amended claim 14; claim 17 subdivided into amended claims 15, 16 and 17; new claims 20 and 21 added."

"Statement under article 19(1)" (Rule 46.4)

The amendments may be accompanied by a statement explaining the amendments and indicating any impact that such amendments might have on the description and the drawings (which cannot be amended under Article 19(1)).

The statement will be published with the international application and the amended claims.

It must be in the language in which the international application is to be published.

It must be brief, not exceeding 500 words if in English or if translated into English.

It should not be confused with and does not replace the letter indicating the differences between the claims as filed and as amended. It must be filed on a separate sheet and must be identified as such by a heading, preferably by using the words "Statement under Article 19(1)."

It may not contain any disparaging comments on the international search report or the relevance of citations contained in that report. Reference to citations, relevant to a given claim, contained in the international search report may be made only in connection with an amendment of that claim.

Consequence if a demand for international preliminary examination has already been filed

If, at the time of filing any amendments under Article 19, a demand for international preliminary examination has already been submitted, the applicant must preferably, at the same time of filing the amendments with the International Bureau, also file a copy of such amendments with the International Preliminary Examining Authority (see Rule 62.2(a), first sentence).

Consequence with regard to translation of the international application for entry into the national phase

The applicant's attention is drawn to the fact that, where upon entry into the national phase, a translation of the claims as amended under Article 19 may have to be furnished to the designated/elected Offices, instead of, or in addition to, the translation of the claims as filed.

For further details on the requirements of each designated/elected Office, see Volume II of the PCT Applicant's Guide.

**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☐ **BLACK BORDERS**

☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☒ **FADED TEXT OR DRAWING**

☒ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**

☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** _____

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.